Research on the development of water retaining materials for water retaining pavement

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ABSTRACT

Water retaining pavement is a pavement to lower the surface temperature by using evaporation of the water that the pavement contains when the pavement is heated by the sun in the daytime. To improve its performance, the capability of absorbing water must be excellent. If most materials which are excellent to absorb water contact with water, their volume is expended and they absorb water to 2~3 times of their volume.

Water retaining pavement permeates cement paste mixed with cement and water retaining materials which are excellent to absorb water into asphalt mixture having air void more than 20%. But the performance of water retaining materials keeps going down because water retaining materials exist independently in cement paste and have no space for expending their volume when they contact water.

Therefore in this study, we developed the foamed concrete which has own air void and evaluated the performance of water retaining materials using super absorbent polymer which is more excellent to absorb water than the existing one. As a result, it was evaluated in maximum absorption rate and water absorption speed being very excellent rather than existing one.

1. INTRODUCTION

One of the by-products of urbanization and industrialization is the heat island effect, which are accelerated by artificial surface (surface coating with a concrete), less natural environment such as greenery/water, heat emissions by air conditioning system and cars that all cause the local temperature to get higher in the big cities. Such huge temperature increase in the cities adversely impacts the ecosystem and living environment in different ways as well as aggravates air pollution.

Heat island effect is largely triggered by concrete and asphalt coating on the road surface and less greenery. Such requires various technologies to efficiently reduce heat island effect, of which afforestation of buildings in the cities and heat island reducing pavement such as water retaining pavement are drawing attention as new alternatives.

Water retaining pavement, which is one of the pavements to reduce heat island, absorbs water to the inner pavement. When sunlight heats the pavement during the daytime, water changes into heat of evaporation, thus lowers temperature of the road surface. In addition, water retaining pavement is an environmentally-friendly technology that absorbs rainwater, which hitherto just ran all the way down to rivers, into the pavement and circulates to the air.

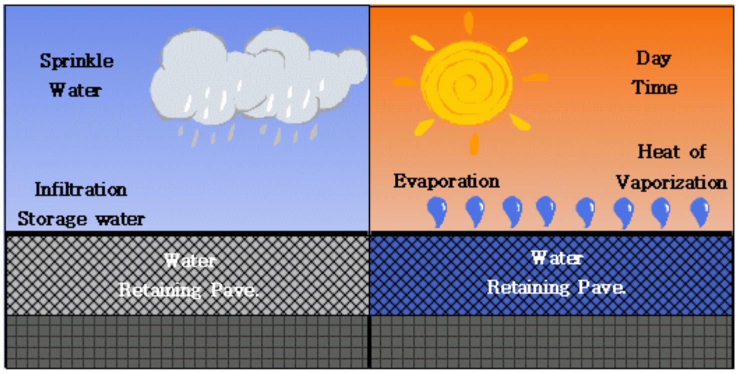

Figure 1. Concept of water retaining pavement

The purpose of this research is to develop water retaining materials that fill the air void of asphalt in water retaining pavement to be applied in Korea. For this, it is a prerequisite to secure fluidity for construction and develop water retaining materials for better water retaining performance as well as quick hardening cement paste to ensure road opening at the earliest time possible. The key to this research is development of water retaining materials that hold big amount of water and boost sustainability since the major function of water retaining pavement is reduction of heat island by retaining water.

One of the most common method of water retaining pavement technology is filling water retaining materials to the air void (20~25%) in asphalt concrete pavement to absorb water. Such asphalt water retaining pavement is split into asphalt concrete and water retaining materials. Materials that retain water (hereinafter, water retaining materials) include grout and fine-grained materials mixed with minerals or resin. Water retaining mechanism is different for each water retaining materials but those that can satisfy water retaining performance specified in Table 1 should be used.

Table 1. Standards of water retaining mixtures

Category		Standard property	Remarks
Max. water retaining amount	(kg/㎡, thickness of water retaining layer = 5cm)	Above 3.0	
Friction coefficient	(μ, speed limit of roads)	Above 0.35	DF tester

2. DEVELOPMENT OF WATER RETAINING CEMENT PASTE

Cement paste is used to inject water retaining materials that have strong absorption power to asphalt air void and ensure stable maintenance. It is therefore necessary to focus development of water retaining materials on two areas: quick hardening cement to accommodate early road opening, durability and water retaining material for better absorbing power; performance of cement paste mixing both materials.

2.1 Development of quick hardening cement

Mixing such various materials as early strength cement, retarder, foaming agent and ultra quick hardening admixture to ordinary portland cement (OPC) and adding a few number of foaming agents were brought to review for developing quick hardening cement to be used for water retaining pavement. Literature survey and preceding research data were used to determine a rough mixture ratio of materials to be used for quick hardening cement. P-Lot was carried out to perform fluidity review on the mixture and quick hardening time was gauged by making an unaided eye observation and touching to verify quick hardening performance, both of which served as the basis to select materials to be used.

2.1.1 Determining W/C

A key factor to be determined ahead of anything else for cement paste is W/C. Fluidity is a critical part of securing work efficiency for water retaining cement paste, which has to be filled to asphalt air void. It is for this reason that W/C was selected as the first determinant factor.

Table 2. P-Lot test result

W/C(%)	Standard	50	55	60	65	70	75
P-Lot (sec)	9～14	14.22	13.12	12.66	11.30	10.98	10.88

While higher W/C gives chances of greater fluidity, it leads to more frequent bleeding, bigger dry shrinkage and less strength.

W/C above 55% satisfies the requirement, according to P-Lot test result. Cement paste fluidity has a huge impact to the water retaining performance not just because of its workability but is filled to asphalt pavement and is therefore important for it to secure fluidity higher than the lowest limit baseline. Fluidity corresponds to W/C but the drop in P-Lot slows down from W/C above 65%, which justified the research to set W/C 65% or above as the basis.

2.1.2 Quick hardening cement mixture rate test

Early strength cement, retarder, ultra quick hardening admixture, ordinary portland cement and foaming agent were used to carry out preliminary test to determine tentative cement mixture ratio. Literature survey and preliminary mixture test were carried out during the process to minimize the multiple test factors. The characteristics of strength were observed to make a more quantitative (objective) evaluation of the superior mixture.

Table 3 shows the cement mixture rate. Early strength cement, retarder and ultra quick hardening admixture were combined as quick hardening materials. 100% W/C was applied for all mixture rates.

Table 3. Test result of water retaining cement paste intensity

	Mix1	Mix2	Mix3	Mix4	Mix5
Quick hardening materials (%)	25	27	30	33	40
OPC(%)	75	73	70	67	60
Strength of age, day 1(MPa)	0.00	0.00	0.00	1.96	2.00
Strength of age, day 3(MPa)	0.78	0.32	0.74	2.42	3.18
Strength of age, day 7(MPa)	0.80	1.16	1.08	2.52	3.19
Hardening time(min.)	47	42	38	32	17

For Mix 1 ~ 3, amount of quick hardening materials was less than 30%, which made it nearly impossible to measure strength of age for day 1. For Mix 5, hardening time was less than 30 minutes, which is too short to secure work time and ratio of expensive quick hardening materials made it an uneconomic choice. For this reason, Mix 4 was tentatively selected as the 1st quick hardening cement mixture considering strength manifestation and hardening time.

2.1.3 Water retaining cement paste test

A cement paste property test and absorption performance test were conducted to a water retaining cement paste that mixed foaming agents and water retaining materials to form quick hardening cement and water channel. The mixture reviewed in this stage is shown in Table 4.
Mix 1 is the basic cement paste mixture rate determined by hardening time, P-Lot and observation of the bleeding with an unaided eye.

Mix 2 is the mixture to determine impact of liquified materials since both solidified and liquified materials exist in water retaining materials. Mix 4,5 and Mix 5,6 were designed to check any changes in characteristics of cement paste using foaming agents and water retaining materials, respectively.

Table 4. Compressive strength and P-Lot result with 1st mixture

		Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6
Quick hardening dement		100	100	100	100	100	100
W/C		65	65*	60	65	65	75
Foaming agent		0	0	1.5	1.5	0	0
Water retaining materials		0	0	0	0	44	44
Compression intensity (MPa)	1 day	4.62	4.14	3.30	2.54	1.26	0.60
	3 days	9.04	8.56	5.32	4.12	1.72	1.00
P-Lot (sec)		10.28	10.35	10.48	9.84	11.76	9.38

* Water used in Mix2 is a mixture of water and water retaining materials solvent at the ratio of 85:15

Foaming agents cause W/C fall or strength decline by boosting fluidity while water retaining materials cause W/C increase and substantial reduction of strength as it absorbs moisture.

Table 5 is the mixture ratio of cement paste for absorption test

Table 5. Mixture ratio for absorption test

Materials \ Mixture	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8
Quick hardening cement	100	100	100	100	100	100	100	100
W/C	65	100	65	65	75	75	65	100
Water retaining materials	0	0	0	0	44	22	44	44
Foaming agents	0	0	1.5	2.5	0	0	1.5	1.5

Maximum absorption rate for Mix 8 recorded 54.7%, which is higher than 52.5% (reference to report by Korea Institute of Construction Technology) from the test result of water retaining paste in Japan.

The absorption test device of Japan Water Retaining Pavement Research group was used to gauge the amount of water the sample absorbs by continuously supplying certain amount of water. With the water measured for each time, the formula below were used to estimate absorption height.

$$\text{Max. absorption rate(\%)} = \frac{\text{Standard dry mass after 24 hours of water cushion - dry mass}}{\text{Sample volume}} \times 100$$

$$\text{Absorption height(cm)} = \text{Sample height} \times \frac{\text{Absorption amount of each absorption time}}{\text{Max. absorption amount}}$$

Table 6. Absorption test result

	Time(min.)	MIX 1	MIX 2	MIX 3	MIX 4	MIX 5	MIX 6	MIX 7	MIX 8
Absorption amount (g)	0	0	0	0	0	0	0	0	0
	10	9.03	28.37	10.87	8.50	28.13	19.90	20.77	45.10
	30	14.27	43.87	16.70	13.00	43.33	30.70	34.07	70.63
	60	18.83	58.10	21.63	17.20	58.40	41.57	47.37	95.97
	120	27.03	81.73	30.30	24.57	84.93	61.13	70.60	137.03
Absorption height (cm)	Time(min.)	MIX 1	MIX 2	MIX 3	MIX 4	MIX 5	MIX 6	MIX 7	MIX 8
	0	0	0	0	0	0	0	0	0
	10	2.2	4.6	2.6	2.3	4.0	3.3	3.0	5.2
	30	3.4	7.1	4.0	3.4	6.1	5.1	4.9	8.1
	60	4.5	9.3	5.2	4.6	8.3	6.9	6.9	11.0
	120	6.5	13.1	7.2	6.5	12.0	10.1	10.2	15.7
Max. absorption rate	(%)	26.1	38.9	26.1	23.6	44.1	37.7	43.2	54.7

W/C for quick hardening cement rose from 65% to 100% in Mix 1 and Mix 2 but absorption amount and absorption height jumped 3.1 times and 2.1 times, indicating that W/C is a key factor determining absorption performance.

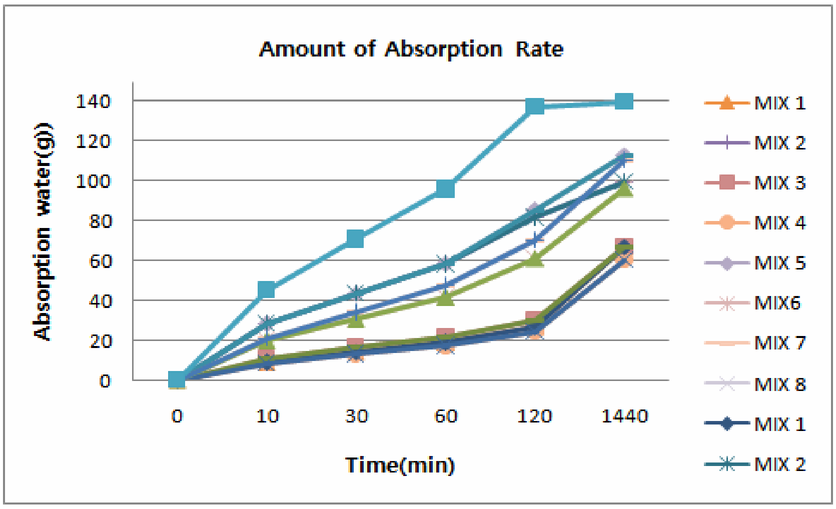

Figure 2. Absorption amount test result

Test result shows that the amount of water retaining materials and W/C (amount of water) are the key factors impacting absorption performance. The amounts of water retaining materials and W/C have to be increased taking into account the economics and performance to deliver better absorption performance. More water retaining materials and water lowers strength of cement paste to a considerable extent causes excessive bleeding and dry shrinkage. Mixture ratio of quick hardening cement was readjusted due to the water retaining materials used for better water retaining performance and due to increased W/C(100%). The readjustment through the test is shown in Table 7.

Table 7. Final mixture ratio test of quick hardening cement

	MIX 1	MIX 2	MIX 3	MIX 4	MIX 5
Early strength cement (%)	0	-3	-3	-5	-5
Ultra quick hardening admixture (%)	0	+0.5	+1	+0.5	+1
Hardening time(mm)	34	23	15	31	21
shrinkage(mm)	-1.7	-0.4	0	-0.5	-0.2

In the existing mixture, a sample was manufactured for the 5cm cube mold to accommodate the increased W/C. It went under atmospheric curing for 24 hours followed by deformation to estimate the height, which showed -1.7mm of shrinkage. A performance comparison was carried out by reducing early strength cement and instead adding ultra quick hardening admixture, which rapidly manifests strength, in the mixture. Decrement (%) in the early strength cement and use(%) of ultra quick hardening admixture, which was added in the existing quick hardening cement mixture ratio, were given modification to perform a test.

Just like the preceding test, hardening time was determined by observation with an unaided eye and inter-penetration of the stick. Shrinkage amount was defined as the difference with the standard 5cm by gauging height of the sample.

Test results showed that while amount of bleeding and shrinkage was small for MIX 2,3 and 5, its hardening time was too short. On the contrary, hardening time for MIX 4 was 30 minutes and shrinkage amount was also very small at only -0.5mm, which led MIX 4 to be final mixture for quick hardening cement. It is also a more economic mixture since early strength is reduced by 5% and 0.5% of ultra quick hardening admixture is added.

2,2 Development of water retaining materials

2.2.1 Materials for water retainment

Water retaining materials composite for water retaining pavement are composed of active carbon, sepiolite, super absorbent polymer and fiber to ensure that maximum water retainment amount exceeds 4.0 kg/㎡. With such composite, water pond is formed within the road pavement and fiber is used to create water channel that links together the water ponds to stimulate water diffusion and circulation.

Water pond means highly polymerized organic admixture, which is capable of absorbing water and porous inorganic matters that store the absorbed water, existing within solid cement in the form of a pond.

(1) Active carbon

Figure 3. Active carbon particle

Active carbon has a large particle size and a surface activity. The most desirable porous inorganic matter should have a particle size in the range of 900 ~ 1500 ㎡/g. Figure 2-1 is the enlarged photo of active carbon particle, which is made up of micro pore, transitional pore and macro pore. The latter two are known to absorb and transmit water. It is for this reason that

Porous active carbon, which is outstanding in water absorption and transmission, was selected as the major material for adjusting water retainment ability and absorption speed.

Too much active carbon content enlarges floating to the upper side of paste during the cement paste manufacturing process. This not only compromises strength by causing disproportionate distribution to the upper part of hard cement but also retards cementation, which is adverse to the economics.

(2) Sepiolite

Sepiolite surface has a hydrophile property, which allows it to get wet faster than active carbon upon water contact. Furthermore, the absorbed water is quickly diffused through fibrous transitional pore like a capillary.

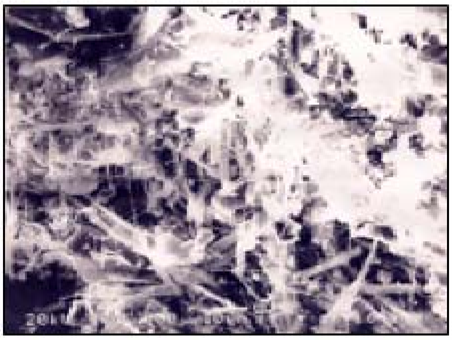

Figure 4. Sepiolite molecular tissue

Since sepiolite has a large particle size, a fibrous molecule that can perform the function of a fiber channel and absorbent at the same time is desirable.

Figure 2-2 shows a sepiolite molecule, which is a natural mineral with a fibrous structure. Unlike active carbon, transitional pores are formed in the molecule.

The sepiolite above is a multi-porous fibrous inorganic matter with a particle size in between 230 ~ 380 ㎡/g. Case in point is magnesium trisilicate ($Mg_4Si_6O_{15}(OH)_2\text{-}6H_2O$).

Sepiolite content less than 10% does not have a huge impact on water retaining performance but a content exceeding 60% undermines workability due to weaker fluidity of cement paste, deteriorates strength of hard cement and retards hardening.

(3) Super absorbent polymer

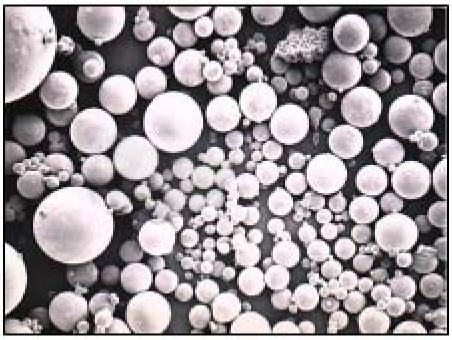

Figure 5. High absorbent polymer particle

An ideal super absorbent polymer is one that performs high absorption power and small loss of water retaining ability in the alkali range. "High absorbent polymer" refers to a synthetic resin capable of absorbing water 50 times its own weight. Poly acrylates resin is the most common type of "super absorbent polymer".

Poly acrylates resin is actually a high molecular material whereby caustic soda is neutralized in the acryl resin to polymerize initiator. The absorbed water runs to the cement's alkali range, which is a slaked lime, to cause shrinkage depriving of the function as an absorbent when mixed to the cement paste.

On the contrary, poly modified acrylic high absorbent polymer adjusts crosslinking density and caustic soda neutralization rate. At the same time, it modifies part of acrylic acid into unsaturated vinyl group, which dramatically solved the problem of discharge of water absorbed in the cement's alkali range.

When the content of super absorbent polymer is less than 1.0%, the efficacy is almost zero. On the contrary, when the content is above 10.0%, it compromises liquidity of cement paste and causes retardation of the hardening.

(4) Fiber

Figure 6. Fiber particle

Fiber forms an open cell by creating a link between close cell type water ponds within water retaining materials for pavement. This helps absorb and diffuse water.

Figure 2-4 is the enlarged fiber particle. Fiber length is in between 0.01 ~ 5.0mm and in fiber chip form. Natural cellulose fiber, poly propylene fiber, nylon fiber or polyester fiber can be used.

Small fiber content causes efficacy, which creates open cell by linking water ponds, to fall. If, however, the content is excessive, it undermines workability, strength of cement hydration and retards hardening.

2.2.2. Water retaining materials mixture ratio test

Performance of ordinary cement and quick hardening cement was compared to evaluate performance of water retaining materials for pavement. Test on maximum absorption rate and absorption speed to compare performance of different additive composites into water retaining materials was also conducted. Test result of the 1st mixture design is shown in Table 8.

Table 8, Optimal property structure design

Test no.	Cement		Water	Additives	
	Ordinary cement	Ultra quick hardening cement		Type	Input
EX-01	100		80		
EX-02	100		80	Fiber	1
EX-03	100		80	High absorbent polymer	2
EX-04		100	100		
EX-05		100	100	Fiber	10
EX-06		100	100	High absorbent polymer	3

Table 9, Performance evaluation of optimal property structure design

Test no.	Volume	Surface dry weight	Dry weight	Max. absorption rate	Absorption time (1 hr)	Max. water retaining amount
	㎤	g	g	%	kg/㎡	kg/㎡
EX-01	95.6	157	119.8	38.9	5.7	3.9
EX-02	102.7	165.3	113.2	50.7	5.1	5.1
EX-03	112	159.2	102.1	51.0	4.6	5.1
EX-04	180	210	152.2	32.1	13.5	3.2
EX-05	180	275.3	157.8	65.3	36.5	6.5
EX-06	180	282	157.6	69.1	8.2	6.9

Maximum water retaining amount is the value of applied property that took into account air void rate of asphalt when constructed on roads. Its value is different from the absorption speed value measured with the sample.

For example, 36.5kg/㎡ in absorption speed in EX-05 means that it actually absorbs 7.3kg/㎡ per hour during actual construction when asphalt air void rate is 20%. As this exceeds 6.5kg/㎡, the maximum water retaining material amount, it can be deduced that the time capable of reaching maximum water retaining amount in EX-05 is less than one hour.

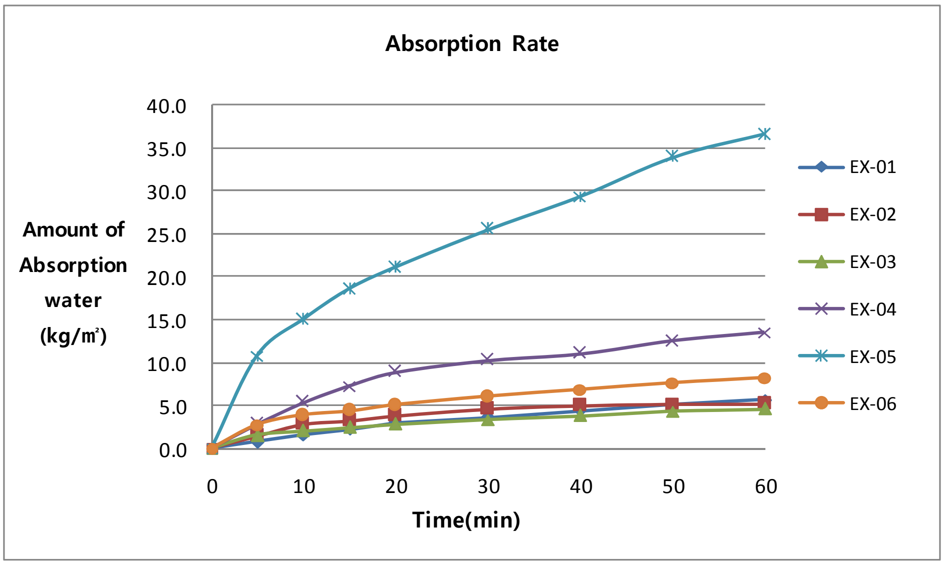

Figure 7. Result of absorption rate test

Analysis of maximum absorption rate found that adding fiber that induces the role of a water-attracting channel (induce capillary and wicking role) and poly, which serves as a tank absorption and retaining water, resulted absorption performance in the range of 50~70%, which is higher than when fiber and poly are not added. This is an outstanding performance far exceeding the target of 40%. For absorption speed, adding fiber induced the role of a wicking through capillary phenomenon, which produced an excellent outcome whereby the speed was three times faster than other tests.

Although cement can absorb water, the void is blocked, which require open cell or channel type additives that can induce and transmit water in order to spread and supply water to a hard cement. This led to the establishment of a mechanism to develop water retaining materials.

A test was carried out on maximum absorption rate and absorption speed in order to make a performance comparison of additives in water retaining materials. The test results of 2nd mixture design are shown in Table 11.

Table 10. Composition of optimal property improvement materials

Test no.	Cement	Water	Additives	
	Ultra quick hardening cement		Type	Input
EX-01	100	100	Fiber 1mm	32
EX-02	100	100	Hydrophobic Fiber	32
EX-03	100	100	Fiber 3mm	32
EX-04	100	100	Fiber 6mm	32
EX-05	100	100	Fiber LC	32

Table 11. Performance evaluation of optimal property improvement materials

Test no.	Volume	Surface dry weight	Dry weight	Max. absorption rate	Absorption speed (1hr)	Max. water retaining amount
	㎤	g	g	%	kg/㎡	kg/㎡
EX-01	180	273.8	157.1	64.8	49.3	65
EX-02	180	253.6	144.6	60.6	37.8	6.1
EX-03	180	279.8	168.8	61.6	45.6	6.2
EX-04	180	280.1	158.7	67.4	57.6	6.7
EX-05	180	267.3	149.9	65.3	54.9	6.5

The variation of absorption speed lied in a wide range of 35~60 kg/㎡ depending on fiber length and type, which essentially serves the role of a water channel making acquisition and distribution among the absorption principles of water retaining materials for pavement. The biggest value was in fiber LC and the fiber length of 6mm.

When fiber length is 6mm, it could cause incongruous combination with cement because of the length and filling rate when filling paste is forecasted to be very low. It is for this reason that the test results of [EX-5], which is over 60% in maximum absorption rate and over 50 in absorption speed (60 min., kg/㎡) with stable property maintenance at the same time, was selected as the most optimal water retaining materials for pavement that can satisfy absorption transmission speed via capillary and strong expansive force, which are the basic concepts of water retaining materials.

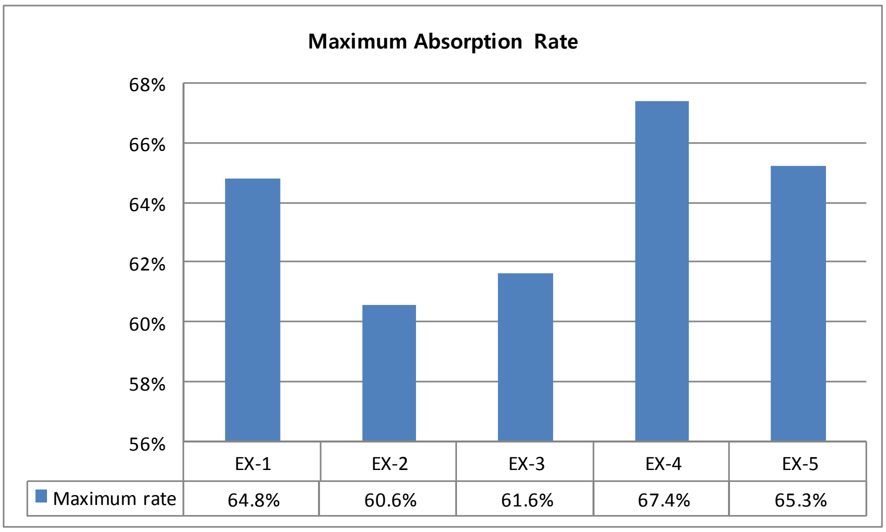

Figure 8. Performance evaluation of optimal property improvement materials –maximum absorption rate

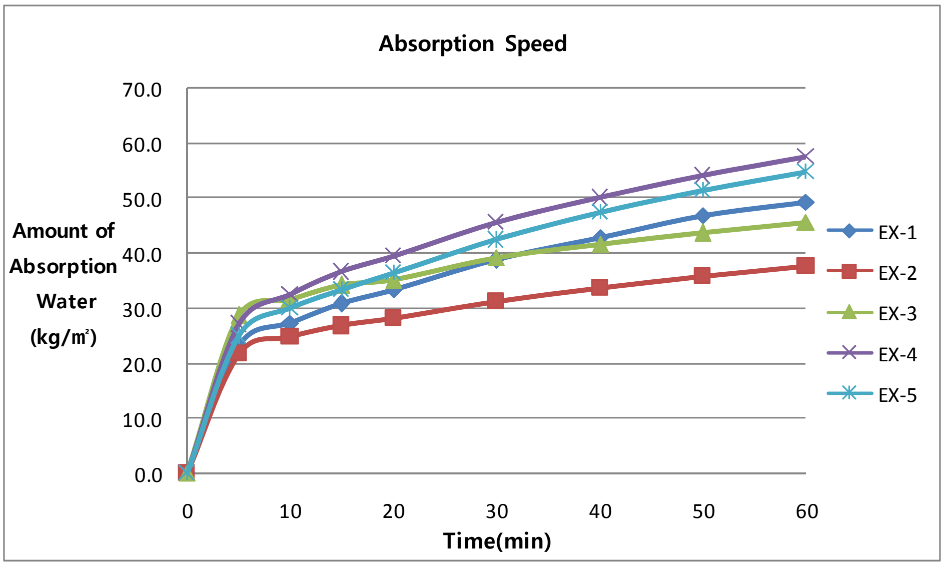

Figure 9. Performance evaluation of optimal property improvement materials –absorption speed

2.2.3 Determining optimal mixture ratio of water retaining materials/cement

Additive composites for water retaining pavement include active carbon, sepiolite, super absorbent polymer and fiber in order to make sure maximum water retaining amount is greater than 4.0 kg/m2. Active carbon, sepiolite and super absorbent polymer help create water ponds within the road pavement materials. Fiber is used to create a water channel that links water ponds, thus ensure smooth diffusion and transmission of water.

Table 12. Mixture ratio of cement/water retaining materials

Test no.	Cement	Water	Water retaining materials for pavement
	Ultra quick hardening cement		Input
EX-01	100	100	44
EX-02	100	100	37
EX-03	100	100	32
EX-04	100	100	30

The test objective is to determine optimal mixture ratio of water retaining materials for pavement and cement by developing mixture of the materials above and their mixture with cement.

Tests on maximum absorption rate and absorption speed were carried out to make a performance comparison of different mixture ratio of water retaining materials/cement. The test result of final mixture design is shown in Table 13.

Table 13. Performance evaluation of water retaining materials/cement optimal mixture

Test no.	Volume	Surface dry weight	Dry weight	Maximum absorption rate	Absorption speed (1hr)	Maximum water retaining amount
	㎤	g	g	%	kg/㎡	kg/㎡
EX-01	180	252.8	134.3	65.9	55.5	6.6
EX-02	180	261.3	138.6	68.2	57.0	6.8
EX-03	180	265.3	145.5	66.6	57.0	6.7
EX-04	180	270.6	158.0	62.6	56.0	6.3

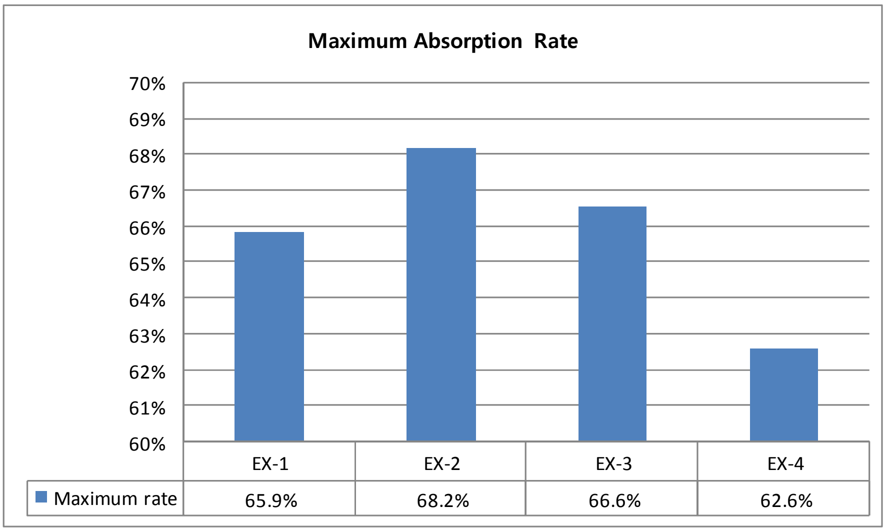

Figure 10. Maximum absorption rate by the mount of water retaining materials

Test result showed outstanding absorption performance of water retaining materials' added amount in the range of 32 ~ 37%, of which 32% was finally selected in consideration of economics and constructability.

Performance test result of water retaining materials that added quick hardening cement and 32% of water retaining materials is shown in Table 14.

Table 14. Performance test result of water retaining materials

Strength of age, day 1	2.027MPa	Max. absorption rate	75.9%	Ordinary cement 59.7%
Strength of age, day 3	2.040MPa	Absorption height after 10 min.	4.6cm	Ordinary cement 2.2cm
Strength of age, day 7	4.867MPa	Absorption height after 60 min.	9.3cm	Ordinary cement 4.5cm

Compressed strength recorded over 2MPa in just one day of strength and a high maximum absorption rate of 75.9%, making it proper for use as water retaining materials for pavement.

3. CONCLUSIONS

The research concluded to set W/C of water retaining pavement materials at 100% given the fluidity and water retaining performance. Accordingly, paste shrinkage reduction, working hours and traffic opening hours were taken into consideration to adjust quick hardening and determine mixture ratio.

W/C was the most important factor impacting water retaining performance followed by water retaining materials, cement and foaming agents. It also delivered better water retaining performance than the water retaining cement in Japan, which was the original benchmark target.

Optimal mixture property of water retaining materials for pavement against cement was achieved when water retaining materials were in the 32 ~ 37% range (against cement).

Assuming above 60% of maximum absorption rate and 50 kg/㎡ of absorption speed is the most ideal basis for water retaining materials for pavement, minimum added content accounting for water retaining materials' field application was 32% relative to cement.

Under the same condition, maximum water retaining amount stood at a very high value of over 6.0 kg/㎡, which is far greater than 4.0 kg/㎡ set as the original target of this research, thus helping acquire a complete new concept of water retaining materials for pavement.

It was therefore agreed to select water retaining materials for pavement that acquired over 60% of maximum absorption rate, over 50kg/㎡ in absorption speed(60min.), maintained stable property with outstanding field applicability and quick absorption/transmission speed supported by strong absorption power and capillary, which are the basic concepts of water retaining materials for pavement.

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